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ORIGINAL PAPER

Deforestation effects on biological and other important soil properties in an upland watershed of Bangladesh

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Abstract: Deforestation occurs at an alarming rate in upland watersheds of Bangladesh and has many detrimental effects on the environment. This study reports the effects of deforestation on soil biological properties along with some important physicochemical parameters of a southern upland watershed in Bangladesh. Soils were sampled at 4 paired sites, each pair representing a deforested site and a forested site, and having similar topographical characteristics. Significantly fewer ($p \leq 0.001$) fungi and bacteria, and lower microbial respiration, active microbial biomass, metabolic and microbial quotients were found in soils of the deforested sites. Soil physical properties such as moisture content, water holding capacity, and chemical properties such as organic matter, total N, available P and EC were also lower in deforested soils. Bulk density and pH were significantly higher in deforested soils. Available Ca and Mg were inconsistent between the two land uses at all the paired sites. Reduced abundance and biomass of soil mesofauna were recorded in deforested soils. However, soil anecic species were more abundant in deforested soils than epigeic and endogeic species, which were more abundant in forested soils than on deforested sites.

Keywords: deforestation effects, biological properties, soil animals, upland watershed, Bangladesh

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Introduction

Bangladesh is in South Asia and has a monsoon tropical climate. The deforestation rate has reached an alarming stage in this Country. Upland watersheds of the country consist of low to very high hills and are mainly located in the southeast. In the distant past this are supported rich natural forest but now faces more severe deforestation than other parts of the country. In 1927, when the Indian Forest Act of 1878 was revised, forest cover of Bangladesh was 20% and has since declined to 6% in natural trees (FMP 1993). Several causes contributed to rapid deforestation, including increased inhabitation of forest land, rapid population growth, clear felling of trees in natural forest with associated burning of remaining vegetation after slashing followed by plantation of exotic species, over exploitation, illicit felling, cutting and lopping of trees, excessive grazing, conversion of forest to agriculture and shifting cultivation. Among these causes, the greatest contributor to deforestation was clear felling of natural forest consisting of locally valuable species, *viz*. *Dipterocarpus turbinatus* (Garjan), *Gmelina arborea* (Gamar), *Artocarpus chaplasha* (Chapalish), *Toona ciliata* (Toon), *Albizia spp*. (Koroi), *Bombyx ceiba* (Simul), *Swintonia floribunda* (Civit), *Tetrameles nudiflora* (Chandul) and *Michelia champaca* (Champa). This was followed by planting for commercial harvest with the objective of achieving higher yields on shorter rotations by planting monocultures of fast growing exotics, mainly *Tectona grandis* (teak) from 1871 and subsequently *Acacia auriculiformis*, *A. mangium* and *Eucalyptus camaldulensis* until 1988. This silvicultural system was characterized by poor management, weak law enforcement, and increased encroachment of habitation. This led to plantation failures that encouraged people to cultivate newly opened fertile valleys and later the adjacent low hill slopes where the plantations had failed. Subsequently, many distressed people moved to the deforested hills from distant districts of the country where river bank erosion and other natural calamities forced them to emmigrate. Many refugees also arrived from neighboring Myanmar and settled the deforested lands. The land

area affected by deforestation remains either unsurveyed or unmapped and never quantified except by periodic ocular estimates. Thus, the different estimates of deforestation reported in various sources are not consistent with one another (FMP 1993; Gain 2002). The estimated deforestation of about 8,000 ha·a^{-1} during the 1970s increased to about 37,600 ha·a^{-1} in the 1980s (FMP 1993). The annual rate of deforestation in Bangladesh was very high (3.3%) compared to six other South Asian countries (0.6%) during 1981−1990, and increased thereafter (FMP 1993). The obvious effect of deforestation in most places is the complete loss of trees with understory vegetation and in some places only bushy vegetation without continuous tree cover. The deforested areas are under intense pressure of repeated grazing from nearby densely populated villages. The other effects are loss of forest litter, compaction and erosion of soil, formation of gullies between the hill slopes and deposition of sediments on valleys and channels. Deforestation also degrades soil quality through loss of organic matter and nutrient elements with the removal of forest vegetation and fertile topsoil (Pritchett and Fisher 1987). Changes in soil physico-chemical and biological properties due to deforestation have been reported (Sahani et al. 2001; Hajabbasi et al. 1997; Ellingson et al. 2000; Thuille et al. 2000). Bulk density is usually higher in deforested sites due to the compaction caused by mechanical harvesting. Opening of the canopy through deforestation changes the microclimatic condition and causes abrupt shifts in soil temperatures, moisture, and the biogeochemical processes dependent on these environmental factors.

Soil respiration is one of the important processes affected by vegetation removal. Soil respiration reflects the capacity of soil to sustain plant growth, soil fauna, and microorganisms. It indicates the level of microbial activity and soil organic matter content and its decomposition stage. Good forest cover contains high levels of organic matter, possesses more roots and plant residues, and favors high levels of microbial activity (Sahani et al. 2001). Deforestation, in contrast, ceases litter input and changes soil respiration by moderating litter decomposition rates. Soil respiration is usually higher during the first few years after deforestation due to the higher temperatures and moisture content that favor microbial degradation of residual organic matter from timber harvest. However, soil respiration can be lower where all or most of the organic matter is removed during deforestation (Sahani et al. 2001).

Litter decomposition, a major pathway of soil respiration, releases CO_2 to the environment, simultaneously releasing or immobilizing mineralized nutrients. Depending on the substrate quality, these nutrients, especially N can be immobilized by microbes and subsequently released to the environment after the death of microbial cells. Nitrogen is either mineralized or immobilized by microbial respiration (Vance et al. 2001). Rates of soil respiration are associated with rates of microbial turnover and nitrogen mineralization (Vance & Chapin. 2001).

Although researchers have investigated degradation of soil physico-chemical properties on forest lands in upland watersheds of Bangladesh (Zaman et al. 2010; Biswas et al. 2010; Haque and Karmakar 2009; Biswas and Choudhury 2007; Chowdhury et al. 2007a, 2007b; Amin et al. 2002), few reported the effects of deforestation on soil biological properties. Recently, however, the effects of shifting cultivation on soil biological properties have been reported for mountainous watersheds of Chittagong Hill Tracts of Bangladesh (Miah et al. 2010; Haque et al. 2012). In this area, shifting cultivation has been the dominant form of agriculture by indigenous people over the last centuries. The objective of the present study was to assess the effects of deforestation on soil biological properties along with other important physicochemical parameters in the Chittagong region under the population pressure of >8 million at present compared to 1.3 million in 1901 (Wikipedia 2010).

Materials and methods

Site description

We sampled soils at 4 paired sites, two from Dulhazara and one from Tankawati in Chittagong district and one from Ghagra in Rangamati district. All paired sites were on upland watersheds of Chittagong and Chittagong Hill tracts. Descriptions of each site are given below:

Deforested land at Dulhazara with adjacent bamboo-dominated forest

The first deforested land was situated to the north-east of Safari Park, Dulhazara, Cox's Bazar at 21°40′08″ N and 092°04′53″E on gently sloping (2%) well drained land. The area lacked trees but was covered to about 1.5 m height in partially burnt vegetation mainly consisting of herbs and shrubs in patches. Grass coverage was 30% and litter cover was 1 cm thick at a biomass density of 400 kg ha^{-1}. During our soil sampling graziers were burning vegetation with the aim of growing new shoots that would be more palatable to their livestock. About 30 years earlier this deforested site had ecological conditions similar to those of today's Safari Park, a protected area adjacent to the study area and supporting natural *Dipterocarpus turbinatus* (garjan) forest.

The adjacent tree covered area was Dulahazara natural garjan forest located at 21°40′10″ N and 092°05′02″ E and now managed as a Safari park under full protection from any biotic interference. This forest land was on gentle slopes (2%) with bamboo coverage of about 70%. C*alamus viminalis* (cane) and other shrubs occupied 12% and trees occupied the rest. Tree canopy coverage at this site was 30% with undergrowth coverage of 90% without any grasses. Diameters of *D. turbinatus* trees ranged from 12 to 75 cm and heights ranged from 15m to 29 m. Because tree sizes varied greatly, the number of trees per unit area ranged from 150 to 225 per hectare. Uniform litter depth was 3.67 cm at a biomass density of 5323 kg·ha^{-1}.

Deforested land at Dulhazara with adjacent D. turbinatus dominated forest

The second deforested site was on low hills at 10 m above mean sea level and adjacent to Dulahazara Safari Park, Cox's Bazar and 20 m west of the first deforested site (above). This defor-

ested site was on slopes of 0 to 4% had no trees, and vegetation consisting of herbs and shrubs grew to heights of 1−2.5 m giving coverage of 30% to 40%. Litter was completely burnt and ashes were present on the surface.

The adjacent tree-covered Dulahazara Safari Park was natural *D. turbinatus* forest on low hills at 10 m above mean sea level on 0−2% slope at 21°40'24"N and 092°05'17"E. This site of natural forest was dominated by *D. turbinatus* with canopy coverage of 60% and undergrowth coverage varied from 40%−70% and had no grasses, but was almost fully (80%) covered with litter. *Malastoma malabaricum* (bontez pata), *C. viminalis* and other herbs constituted 40% as undergrowth. Tree size varied greatly in this natural forest and diameters of *D. turbinatus* ranged from 43-80 cm while heights ranged from 16 to 21 m. Large trees (>60 cm dbh) accounted for 21% of all trees and the remaining trees were medium-sized. Tree density varied from 200 to 375 per hectare. Litter cover was almost uniform with a depth of 4.5 cm and mean litter biomass density of 6296.7 kg·ha^{-1}.

Deforested site at Tankawati with adjacent natural forest

This small site was at 21°58′628″ N and 092°11′669″ E, beside Tankawati natural forest, Padua Range under Chittagong South Forest Division. The site was on a flat hill of westerly aspect. This was barren land with no trees, but with grass coverage of 80% and little or no herbaceous vegetation.

Adjacent natural forest at 21°58′702″N and 092°11′745″E was covered with *D. turbinatus* trees. This forest was on a medium hill having 12% slope. This forest was mostly *D. turbinatus* and other tree species, including *Artocarpus chaplasha* (chapalish), *Clerodendrum viscosum* (bhat), *Tetrameles nudiflora* (chandul), at 70% tree canopy coverage and 50% undergrowth coverage. Litter cover was 8 cm thick and biomass density was 620 kg·ha^{-1}.

Deforested land at Ghagra with adjacent 8 year old mixed plantation

This deforested site was located at Ghagra, on the way to Kaptai, Phulgaji Range under Jhum Control Division at Mulari para, 100 No. Wagga Mouja, Kaptai at 22°38′672″ N and 092°05′823″ E. This was a steep high hill of southeasterly aspect. The area was recently deforested and remained fallow for about 2 years. The land was fully exposed to sunlight without any ground vegetation.

Adjacent forest land was a 10 year old mixed plantation of *Gmelina arborea* (gamar), *Tectona grandis* (teak), *Albizia lebbeck* (koroi) and by wild banana at 22°39′216″ N and 092°07′547″ E on a steep high hill of northeasterly aspect. Canopy coverage was 55% with 40% ground vegetation consisting mostly of *C. viscosum*, *Eupatorium spp.* (asamlata) and other herbs with a litter depth of 1 cm.

Soil sampling and analysis

From the four paired sites 5 replicated soil samples were collected from a depth of 0−5 cm, mixed thoroughly to give a composite sample and brought to the laboratory in labeled polythene bags that had been sterilized with 95% ethyl alcohol. In the laboratory, samples were divided into two sub-soil samples: one used for the determination of physical and chemical properties and the other kept in refrigerator at 4ºC temperature for determining biological properties.

Determination of physico-chemical properties

Moisture content was determined drying the soil in an oven at 105°C for 8 hours. Bulk density of soils was determined by the core method. Moist soil pH was determined using a TOA pH meter in triplicate at 1:2 soil-water ratios. Electric conductivity was measured using a digital conductivity meter (TOA, Japan). Soil organic carbon and organic matter were determined using the loss on ignition method according to Ball (1964) and total nitrogen by the micro-Kjeldahl method (Jackson 1973). Available phosphorus was extracted with Bray and Kurtz No.2 extractant and measured by $SnCl_2$ reduced molybdophosphoric blue color method using a spectrophotometer (Jackson 1973). Available calcium and magnesium were quantified following Petersen (2002).

Determination of basal respiration

Basal respiration in soil was estimated according to Dubey & Maheswari (2002). One hundred grams of moist soil was taken into a sterile 500 mL conical flask. Three test tubes, each containing freshly prepared 10 mL of 1N-NaOH, were placed inside this conical flask. Each conical flask was then closed with a rubber stopper and sealed with wax. A set of blank experiments was run as the control. The conical flasks were then incubated at 30°C for 7 days, after which the 1N-NaOH solution was removed from the test tube and titrated against 0.1N-HCl in a conical flask adding 2 or 3 drops of phenolphthalein indicator. The end point of the reaction turned from pink to colorless. The basal respiration was calculated from the following relationship:

$$C_R = \frac{C_1 - C_2}{I} \quad (1)$$

where, C_R represents basal respiration, C_1 represents evolution of CO_2 from soil, and C_2 represents atmospheric CO_2 absorbed by 1N-NaOH and I represents incubation period

Active microbial biomass

Active microbial biomass (C_{AMB}) of soil was quantified using the Van de Werf & Verstrate (1987) glucose-amendment method, which is also known as substrate-induced respiratory assay. Approximately 0.2 g talc and 0.03 g glucose were ground and thoroughly mixed with 20 g moist soil and taken into a 500 mL conical flask. Exactly 10 mL standardized 0.1N-NaOH was taken in each of the triplicate test tubes to trap CO_2 and placed into the conical flask. Conical flasks were then sealed with wax and incubated for 10 hours at room temperature (25±1) ºC. After incubation the amount of evolved CO_2 was measured after titration of the content against N/10 HCl. The active microbial biomass (C_{AMB}) was calculated from the following formula:

$$C_{AMB} = (C_{am} - C_{uam}) \times A_C \quad (2)$$

where, C_{am} indicates evolution of CO_2 from the glucose-talc amended soil, C_{una} indicates evolution of CO_2 from soils only (un-amended), and A_C is the coefficient (0.283) to convert CO_2–C into C_{AMB} (Van de Werf and Verstrate 1987).

Metabolic quotient (C_{Res}/C_{Org}) was determined dividing basal respiration ($C_{Res.}$) by organic carbon. Again, microbial quotient (C_{AMB}/C_{Org}) was determined dividing active microbial biomass (C_{AMB}) by organic carbon (C_{Org}) (Anderson and Domsch 1990). Significance of differences between the means of shifting cultivation and those of mixed plantation was determined by one way analysis of variance of triplicate data for each parameter using SPSS 16.0 package.

Microbial population

Potato dextrose agar (PDA) media was used for culturing fungi. For serial dilution exactly 1g sieved soil passed through 2 mm mesh size, was dispersed in 99 mL sterile water in a conical flask to produce 10^{-2} dilution, from which 1 mL suspension was removed using a sterilized pipette and mixed thoroughly adding 99 ml sterile water in another conical flask to give 10^{-4} dilution. In this way dilutions were made up to 10^{-5}. Dilutions of 10^{-3}, 10^{-4} and 10^{-5} were used for culturing and isolation of fungi. Three replicated soil samples were analyzed for each depth and land use for making such dilutions. Exactly 0.1 mL streptomycin sulfate (0.25 mg·mL^{-1}) solution was added and spread on PDA media in Petri-dish to inhibit bacterial growth and was allowed to solidify (Miah et al. 2010).

From the dilution series, 1ml soil suspension was pipetted out and spread over solidified media in Petri-dishes. After 72 hours incubation all Petri-dishes were examined. Petri-dishes which had >300 or <30 colonies on the plates were discarded (Clack 1965). Colonies of diameter greater than 2 cm on any plate were also discarded. Total numbers of colonies on each of the acceptable plates were counted using colony counter and the result expressed as Colony Forming Unit (cfu) according to Clark (1965).

For culturing bacteria, nutrient agar (NA) media was used and dilutions were made up to10^{-9}. Dilutions 10^{-7}, 10^{-8} and 10^{-9} were used for bacterial culture. Each of the dilutions in conical flasks was shaken vigorously for 10 minutes. Nystate solution (0.005mg·mL^{-1}) was used as antifungal for the culture (Miah et al. 2010). All Petri-dishes were examined after 24 hours incubation.

Soil animals

Soil animals were enumerated at Tankawati by use of the soil monolith and pitfall trap method (Anderson & Ingram 1993). Five soil monoliths, each of 25 cm × 30 cm, were taken at equal spacing in a 40 m × 5 m transect (Fig. 1). Each of the monoliths was then taken out by digging the surrounding soil using a spade and knife. Soil was then pulled out from the monolith and animals counted by species. Isolated soil fauna were then stored in 70% alcohol and carried to the laboratory for determination of fresh weight.

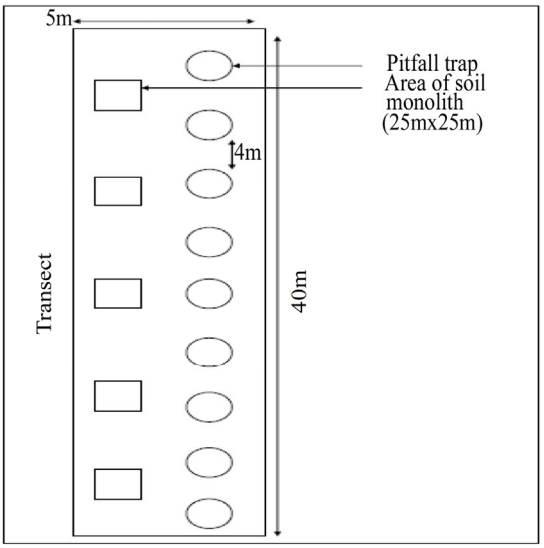

Fig. 1: Layout of pitfall trap and monolith in a 40 m×5 m transect for soil animal study

Ten pitfall traps of 12 cm mouth diameter were installed into soil up to ground level at 4 m intervals within the soil monolith transect. For easy movement of soil animals and camouflaging the trap, pitfall traps were set level with the ground surface. Each trap contained water to 50% of its capacity with a few drops of detergent to attract and trap the soil animals. Traps were kept on the sites from one evening to the next evening to avoid human disturbance. Triplicate data were analyzed using one-way ANOVA in SPSS 16 to assess difference between means for land uses.

Results

Physical properties

At all 4 paired sites, viz. Dulahazara 1, Dulahazara 2, Tankawati and Ghagra, deforested soils contained significantly lower moisture ($p \leq 0.05$) and maximum water holding capacity ($p \leq 0.001$) and significantly higher bulk density ($p \leq 0.001$) compared to adjacent forest soils (Table 1). In deforested soil, moisture content, bulk density and maximum water holding capacity at Dulahazra1 were 4.98%, 1.52 g·cm^{-3} and 33.03%, respectively. In adjacent bamboo dominated forest their corresponding values were 10%, 1.33 g·cm^{-3} and 36.94%. Similarly, in deforested soil moisture content, bulk density and maximum water holding capacity at Ghagra were 6.40%, 1.66 g·cm^{-3} and 28.70%, respectively, while their corresponding values in adjacent mixed plantation were 16.14%, 1.45 g·cm^{-3} and 48.09%.

Table 1: Soil physical properties in deforested and forested upland watershed in Bangladesh

Location	Land use	Moisture content (%)	Bulk density ($g \cdot cm^{-3}$)	Maximum water holding capacity (%)
Dulhazara 1	Deforested land	[a]4.98***	1.52***	33.03**
	Adjacent bamboo dominant forest	10.00***	1.33***	36.94**
Dulhazara 2	Deforested land	5.24*	1.71***	28.41***
	Adjacent natural forest	7.50*	1.40***	40.76***
Tankawati	Deforested land	4.36***	1.54***	25.61***
	Adjacent natural forest	9.70***	1.22***	30.12***
Ghagra	Deforested land	6.40***	1.66***	28.70***
	Adjacent mixed plantation	16.14***	1.45***	48.09***

Notes: [a]Each value is the mean of 3 replicated soil samples; * indicates significant difference at $p \leq 0.05$ and *** at $p \leq 0.001$.

Chemical properties

Most soil chemical properties differed significantly between deforested land and adjacent forest land. At all four locations, viz. Dulhazra 1 and 2, Tankawati and Ghagra, deforested soil had significantly lower organic matter ($p \leq 0.001$), electric conductivity, total N, available P and significantly higher pH ($p \leq 0.05$ and $p \leq 0.01$) than adjacent forest soil (Table 2). Available Ca and Mg were inconsistent between the two land uses at the paired sites. For example, deforested soil showed higher values of available Ca and Mg at Dulhajra 1 and lower values at Ghagra. At Dulhazra 2 in deforested land organic matter, conductivity, total N, available P were 1.8%, 98 $\mu s \cdot cm^{-1}$, 0.04% and 0.22%, respectively, and in adjacent natural forest they were 2.55%, 165.67 $\mu s \cdot cm^{-1}$, 0.15% and 0.39%, respectively. At Tankawati deforested land contained organic matter 1.94%, electric conductivity 116.33 $\mu s \cdot cm^{-1}$, total N 0.04% and available P 0.17%, while adjacent natural forest contained organic matter 2.07%, electric conductivity 129 $\mu s \cdot cm^{-1}$, total N 0.27% and available P 0.37%. At Dulhazra 2 and Tankawati deforested land had pH of 5.57 and 5.30 and at these two places adjacent natural forest had pH of 5.22 and 4.93 (Table 2).

Table 2: Soil chemical properties in deforested and forested upland watershed in Bangladesh

Location	Land use	pH	Org. matter (%)	Conductivity ($\mu s \cdot cm^{-1}$)	Total N (%)	Available P (%)	Available Ca (cmolc kg^{-1}soil)	Available Mg (cmolc kg^{1}soil)
Dulhazara 1	Deforested land	5.52*	2.75***	111.00***	0.07***	0.31***	1.08***	1.00***
	Adjacent bamboo dominant forest	5.10*	3.41***	233.67***	0.20***	0.45***	0.70***	0.28***
Dulhazara 2	Deforested land	5.57*	1.80***	98.00***	0.04***	0.22***	1.02	0.56***
	Adjacent natural forest	5.22*	2.55***	165.67***	0.15***	0.39***	1.03	0.50***
Tankawati	Deforested land	5.30*	1.94***	116.33***	0.04***	0.17***	5.25***	1.17***
	Adjacent natural forest	4.93*	2.07***	129.00***	0.27***	0.37***	4.11***	1.11***
Ghagra	Deforested land	5.21**	2.15***	124.33***	0.13***	0.25***	0.32***	0.13***
	Adjacent mixed plantation	4.53**	3.16***	337.00***	0.28***	0.72***	0.64***	0.27***

Notes: [a] Each value is the mean of 3 replicated soil samples; * indicates significant difference at $p \leq 0.05$; ** at $p \leq 0.01$ and *** at $p \leq 0.001$; cmolc kg^{-1}soil indicates centimole concentration per kilogram of soil.

Biological properties

Microbial properties such as fungal and bacterial population, microbial respiration and microbial biomass showed significantly lower values on deforested lands than on forested lands ($p \leq 0.001$) at all four locations (Table 3). At Dulahazra 1 on deforested land, fungal population, bacterial population, microbial respiration and active microbial biomass in soils were 0.95 $\times 10^5$ cfu·g^{-1}, 0.99×10^8 cfu·g^{-1}, 4.12 $kg^{-1} \cdot d^{-1}$ and 94.52 mg·kg^{-1}, respectively. Their corresponding values in adjacent bamboodominated forest in soils were 1.47 $\times 10^5$ cfu·g^{-1} soil, 2.59×10^8 cfu·g^{-1}, 6.06 $kg^{1} \cdot d^{-1}$ and 106.27 mg·kg^{-1}. Similarly, at Tankawati on deforested land fungal population, bacterial population, microbial respiration and active microbial biomass in soils were 1.07×10^5 cfu·g^{-1}, 1.91×10^8 cfu·g^{-1}, 3.95 $kg^{-1} \cdot d^{-1}$ and 68.38 mg·kg^{-1}, respectively; while the corresponding values of these parameters in adjacent natural forest in soils were 2.16×10^5 cfu·g^{-1}, 2.63×10^8 cfu·g^{-1}, 7.81 $kg^{-1} \cdot d^{-1}$ and 114.15 mg·kg^{-1}. At Dulahazra 2 and Ghagra similar differences existed for these parameters between deforested soil and adjacent natural forest or mixed plantation (Table 3). Both respiratory and biomass quotient were lower in deforested soil than forest soil except at Ghagra (Fig. 2 and Fig. 3).

Soil animals

At Tankawati, deforestation reduced both number and weight of earthworms, millipedes, ants, woodlice and bugs, and increased termites in soil (Table 4). At this site the number of earthworms, millipedes, ants, woodlice and bugs per square meter were 11.34

16.35, 40.52, 48.31 and 16.29, respectively, in deforested soil, and they had corresponding values of 70.72, 55.36, 57.12, 97.76 and 65.92 in adjacent natural forest. Similarly, their biomasses were lower in deforested soil compared to natural forest (Table 4). Number of soil epigeic and endogeic species decreased and anecic species increased in deforested soil compared to adjacent natural forest (Table 5). The numbers of epigeic, anecic and endogeic species per kg of soil were 6.65, 0.59 and 1.79, respectively, with their corresponding values of 4.74, 0.20 and 1.87 in forest soil.

Table 3: Soil biological properties in deforested and forested upland watershed of Bangladesh

Location	Land use	Fungal population (cfu·g^{-1} soil)	Bacterial population (cfu·g^{-1}) soil)	Microbial respiration (kg^{-1}·day^{-1})	Active microbial biomass (mg kg^{-1} soil)
Dulhazara 1	Deforested land	[a]0.95×10^{5} ***	0.99×10^{8} ***	4.12 ***	94.52 ***
	Adjacent bamboo dominant forest	1.47×10^{5} ***	2.59×10^{8} ***	6.06 ***	106.27 ***
Dulhazara 2	Deforested land	1.62×10^{5} ***	1.17×10^{8} ***	4.58 ***	88.02 ***
	Adjacent natural forest	1.97×10^{5} ***	2.06×10^{8} ***	7.35 ***	102.37 ***
Tankawati	Deforested land	1.07×10^{5} ***	1.19×10^{8} ***	3.95 ***	68.38 ***
	Adjacent natural forest	2.16×10^{5} ***	2.63×10^{8} ***	7.81 ***	114.15 ***
Ghagra	Deforested land	1.18×10^{5} ***	1.68×10^{8} ***	4.97 ***	98.97 ***
	Adjacent mixed plantation	1.57×10^{5} ***	1.78×10^{8} ***	5.03 ***	87.62 ***

Notes: cfu indicates Colony Forming Units of microbial populations; [a] Each value is the mean of 3 replicated composite soil samples; *** indicates significant difference at $p\leq0.001$.

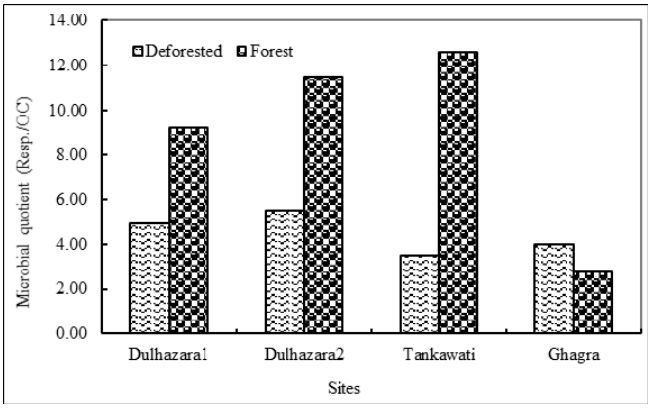

Fig. 2: Quotient of microbial respiration (Resp.) and organic carbon (OC) of soil in deforested land of upland watershed

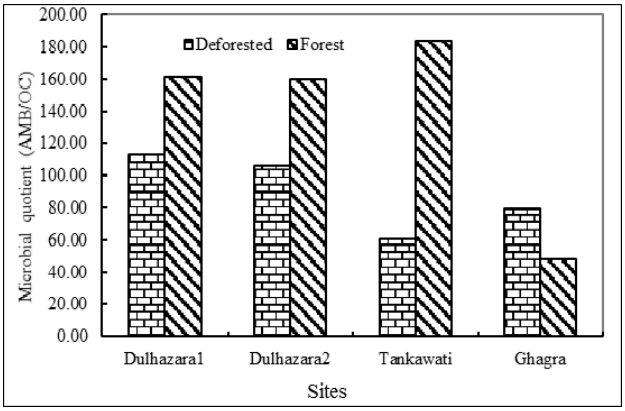

Fig. 3: Quotient of active microbial biomass (AMB) and organic carbon (OC) of soil in deforested land of upland watershed

Table 4: Soil animal population and biomass in deforested and forested land at Tankawati, Bangladesh

Microbe	Number of Population				Biomass (g m^{-3} soil)	
	Deforested soil (m^{-2} land)	Forest soil (m^{-2} land)	Deforested soil (kg^{-1} soil)	Forest soil (kg^{-1} soil)	Deforested soil	Forest soil
Earthworm	11.34**	70.72**	0.34*	1.58*	2.47**	9.77**
Termite	69.12**	24.32**	2.04*	0.49*	0.88*	0.28*
Millipede	16.35**	55.36**	0.45	0.91	1.28**	4.85**
Ant	40.52*	57.12*	3.77*	1.13*	0.52**	5.84**
Woodlice	48.31**	97.76**	1.36*	1.52*	2.52*	5.11*
Bug	16.29**	65.92**	1.07*	1.18*	2.32**	7.11**

Notes:* indicates significant difference at $p\leq0.05$ and ** at $p\leq0.01$.

Table 5: Number of soil macro fauna based on functional group in deforested and forested upland watershed at Tankawati, Bangladesh

Functional group	Deforested soil		Forest soil	
	(m^{-2} land)	(kg^{-1} soil)	(m^{-2})	(kg^{-1} soil)
Epigeic species	121.47	6.65	274.16	4.74
Anecic species	20.39	0.59	8.21	0.20
Endogeic species	60.07	1.79	86.83	1.87

Discussion

Soil physico-chemical properties

Soil physicochemical properties showed marked differences between deforested and adjacent natually forested land (Tables 1

& 2). Significantly higher bulk densityin deforested land at all of the 4 pair sites indicated an increase in soil compactness (Sahani and Behera 2001) which can be attributed to several factors operating together such as lower incorporation of organic matter on the surface, presence of larger roots and trampling by grazing animals, deliberate burning of organic matter by graziers and little litter (400 kg·ha^{-1}) at Dulahazara in deforested land. Soil in natural forest at Dulahazara Safari park in particular was covered by a thick litter layer (5323 kg·ha^{-1}) and completely protected from interference such as collection and burning of litter by people and grazing by animals. This finding was in agreement with several authors e.g. Zaman et al. (2010); Hajabbasi et al. (1997); Liu et al. (2002); Haque (1997); Chowdhury et al. (2007a); Jing-Cheng et al. (2004); Rolfe and Boggess (1973); Sahani and Behera (2001) from Bangladesh and abroad. Along with the increase in bulk density significantly lower moisture content and maximum water holding capacity were also found on deforested land. The low moisture content on deforested sites was due to evaporation caused by direct exposure of soil surfaces to incoming radiation (Lal 1989).

Increased bulk density at the barren site indicated an increase in the soil compactness which confirms the observation of Sahani and Behera (2001), Spaans et al. (1989) that the loss of forest cover increases soil bulk density. Low water holding capacity and low moisture levels of deforested land shows impacts on the hydrological regime as well as poor macro-porosity and infiltration rate (Lal 1996; Sahani and Behera 2001).

Soil organic matter content on deforested lands was also lower than on the adjacent forests due to low input of organic substrate in absence of vegetative cover (Zaman et al. 2010; Hajabbasi 1997; Lugo & Sanchez 1986). Deforestation causes change in the soil microenvironment and leads to breakdown in the decomposition process, which ultimately results in low levels of organic matter and other available nutrients (Basu and Behera 1993). Moreover, organic matter plays a significant role in soil aggregation and contributes to resistance of soil erosion. Therefore, deforested land having low levels of organic matter are more susceptible to erosion than forests. Thus, deforested land causes nutrient loss through erosion. Loss of soil nutrients through leaching on bare land has also been reported by Mroz et al. (1985) and Prashad et al. (1994).

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The surface soil of deforested sites contained significantly lower amounts of total nitrogen and little litter in decomposing stages compared to forest land. The other reason for lower nitrogen content in deforested land might be leaching loss due to high rainfall in the rainy season in this monsoon tropical region. Lower nitrogen content on deforested land was also found when compareing deforested with agricultural land and natural forest with plantations (Zaman et al. 2010; Islam and Well 2000; Hajabbasi 1997; Mroz et al. 1985; Haque 1997). Deforested land in study had lower levels of available P, as reported by Zaman et al. (2010) and Hajabbasi et al. (1997). We found both higher and lower amounts of available Ca and Mg in deforested soil compared to forest soil and this was similar to reports by Zaman et al. 2010; Haque 1997; Rolfe and Boggess 1973, which might be either more uptake of these elements in forested area or site specific reasons.

Soil biological properties

Deforestation reduced the abundance of all kinds of microbes, animal populations, active microbial biomass and basal respiration in soil. This was certainly due to the reduced organic food base and overall ecological differences between the two land uses: deforested versus forested lands. In forests a definite ecological conditions defined by light, moisture, drainage, aeration, organic food materials and both fine and coarse roots determine the type of fauna that can survive. Change in the hydrologic regime and low organic matter levels in deforested land brings change to the soil environment and causes a decline in microbial growth (Basu and Behera 1993; Basu et al. 1992). Forest clearing and conversion to other land uses often result in a depleted microbe populations (Jha et al. 1992) and enzymatic activity (Salam et al. 1998) due to changes in soil microclimates. For such reasons the number and varieties of fauna are much higher in forests than in either deforested or agricultural lands (Pritchett & Fished 1987). Reduced active microbial biomass and basal respiration in deforested land was related to lower organic matter and microbial activity compared to natural forest containing significantly higher amount of organic matter. Similarly, reduced aggregate stability of deforested land is associated with lower input of labile C having lower amounts of litter-fall and root exudates compared to natural forest that is rich in both of the organic substances. Active microbial biomass is usually limited by the availability of labile C (Islam & Weil 2000). Thus, lower abundance of active microbial biomass is an indication of lower aggradations of organic C in deforested land and the reverse is true for natural forest or plantation containing higher amounts of organic carbon.

Microbial respiration was higher at all natural forest sites than on their adjacent deforested lands. High amounts of respiration in forests might be due to high levels of organic matter (litter) inputs that are annually added to the soil surface. Microbial metabolic quotient is an index of evaluation of substrate utilization efficiency in microbial communities (Insam 1990). The more efficient functioning of microorganisms is related with greater fractionation of substrate C incorporated into biomass and less C loss from biomass through respiration, which results in a low metabolic quotient. A high metabolic quotient on deforested land indicated a low efficiency of substrate utilization by soil microbes (Fig. 2). Higher quotients of respiration and active microbial biomass (Fig. 2 & 3) in deforested land compared to forest at Ghagra might be associated with higher active microbial biomass.

The soil animal population and biomass at Tankawati was much lower on deforested land than in forests, except for termites, which might result in slow nutrient mineralization in deforested land. Anderson et al. (1985) suggested that litter-feeding organisms accelerate N mineralization in temperate deciduous woodland. Anderson et al. (1983) demonstrated that the millipede *Glomeris marginata* reduced nutrient immobilization in

temperate deciduous litter and soil, thereby enhancing nutrient fluxes. Effects of such organisms on mineralization might be amplified in the tropics with the abundance of soil macro-fauna (Anderson et al. 1985; Lavelle et al. 1993; Gonza´lez et al. 2001). The higher termite population on deforested land is in agreement with Martins et al. (1996), as this organism generally survives on dead wood materials. They also found larger populations of wood-feeding termites in areas after clearing and burning of rain forest.

Conclusions

This study has shown that deforestation adversely affected important physico-chemical and biological properties such as fungal and bacterial populations, microbial respiration, active microbial biomass and metabolic quotients in soil. These biological properties are related through biochemical processes such as decomposition, nitrification, ammonification, nitrogen fixation, and denitrification in maintaining ecological balance and overall environment in a region. At present deforestation is intense in this important hilly watershed of Bangladesh mainly due to settlement of the rapidly growing human population and clearing of forests to fulfill daily needs along with many other reasons. Few scattered trees remained over most of the watershed although in the distant past all hills were covered with luxurious naturally growing forest. Absence of forests particularly on hilly topography causes many environmental consequences. Given the nature of current global environmental stresses, presence of permanent vegetation, i.e., forests in such hilly watersheds are critically important today. Theoretically this is possible to achieve by encouraging and maintaining natural levels of plant biodiversity on hills following monsoon rainfall in addition to proper management of indigenous tree plantations. Such measures would help to conserve and enhance environments for growing myriads of organisms in soils and hence for overall healthy environment in this hilly watershed. To achieve these benefits, however, requires policy decisions and enforcement of the policy in the country.

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